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## THE HEART AND THE RED BLOOD CELLS AS GENERATOR AND DISTRIBUTORS OF STATIC ELECTRICITY

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### I. A THEORETICAL CONCEPTION

Physiologists are agreed that electric stimulation is the equivalent of physiological stimulation.

Any substance moving through air or through water takes on static charge, and the charge is related to the speed of the movement.

The red blood cells are ideally evolved as receptors and carriers of static charge. This is seen in the extreme thinness of their covering films ( $\frac{1}{2,500,000}$  cm. thick), in their biconcavity, which provides a larger surface per mass, and in their irregular shape, which increases tumbling and friction and thereby produces higher charge.

The irregular cavities of the heart and the heart's contractions form an ideal mechanism for friction and movement, required for accumulating static electricity. The highest electric charge would be expected in the left ventricle, the lowest in the vena cava, since electric charge is highest with the maximum speed of movement. As the red blood cells slow down in passing from the left ventricle to the capillaries, the electric charge is distributed to the walls of the blood vessels and to the tissues beyond. The greatest distribution would therefore occur in the capillaries, where the movement of the red blood cells is extremely slow.

The heart as a generator and the red blood cells as distributors collaborate to stimulate electrically every tissue and organ of the body. As each contraction of the heart contributes electrical stimulation to the entire arterial tree, it establishes

peripheral resistance in the arterial system, required for the proper circulation of the blood. Thus the heart and the red blood cells contribute to the tone and the physiological activity of the entire organism.

The heart responds instantly to various simulations of the environment, such as danger. This response occurs through the special senses, the stimulus passing from the brain over the sympathetic nerves down to the junction between the celiac ganglion and the aortic wall. This junction would seem to be the point of communication between the external and the internal environment of the animal, analogous to the countless nerve end plates between the voluntary nerve fibers and voluntary muscle fibers, which are synaptic junctions between the internal and external environment.

With each pulse of the heart a wave of electrical stimulation is distributed to the vascular walls of the entire arterial tree. Thus the heart contraction sets up its own peripheral resistance, and this resistance sets up stimulating mechanical pressure in turn on the walls of the heart. This would appear to be an important factor in circulation of the blood.

It would appear that the celiac ganglion is the mediator between the sense stimuli of the environment and the electrifier of the organism, the heart and the red blood cells, with their power of generating and distributing static electricity. These conceptions have been tested in the Biophysics Laboratory of the Cleveland Clinic Foundation by Dr. Otto Glasser and Dr. D. P. Quiring

## II. POTENTIAL GRADIENTS OF THE BLOOD AND ORGANS OF CERTAIN MAMMALS

Living organisms have electrical properties. One of these properties is the potential gradient which exists between different organs. This potential gradient lends itself to accurate measurement, and it is characteristic for the organism under investigation and also for the condition it is in at the time of the experiment.

For the determination of potential gradients in living organisms, we have built a microvoltmeter on the general principles suggested by Burr and Lane.<sup>1</sup> This instrument is

<sup>1</sup>Burr, H. S., C. T. Lane, and L. F. Nims: A Vacuum Tube Microvoltmeter for the Measurement of Bioelectric Phenomena. *Yale J. Biol. & Med.* 9: 65-76, 1936.

sensitive and stable and draws a minimum amount of current from the tissue. It consists of a balanced bridge circuit which permits detecting voltage gradients as small as a few microvolts. Contact between the instrument and tissue is made by two reversible, nonpolarizable silver-silver chloride electrodes. These are immersed in a balanced physiological saline solution and are connected through glass and rubber tubing to two glass pipets which are in turn inserted into the tissue. These glass pipets may be variously shaped, depending upon the organs into

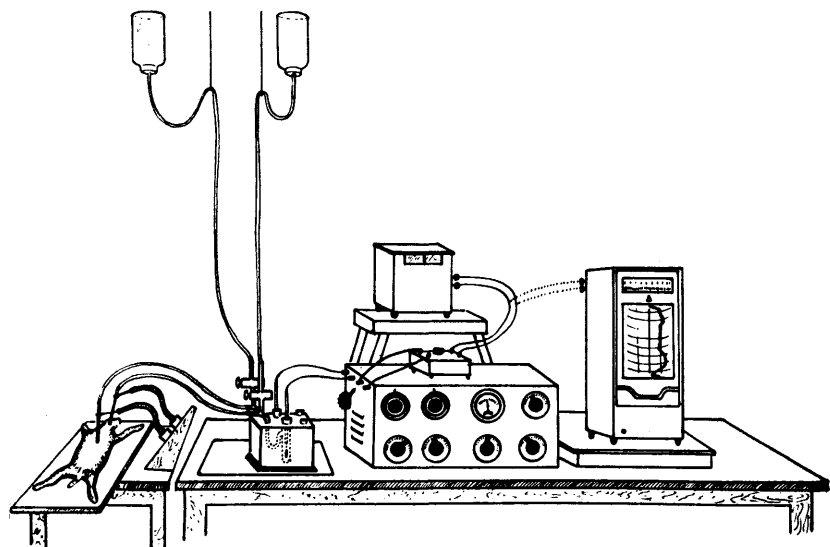


Fig. 1. Microvoltmeter to measure potential gradients in animals.

which they are to be inserted. Readings are taken on a sensitive bridge galvanometer which is directly calibrated in microvolts. For single readings, a Rubicon galvanometer with a sensitivity of about 0.0032 micro-amperes per division, and for continuous records, a General Electric photoelectric recording galvanometer with a sensitivity of about 0.02 micro-amperes per division, were used. Figure 1 shows a schematic diagram of the apparatus.

With this microvoltmeter, potential differences were measured between various points in a series of 265 animals, 245 of which were rabbits. In practically all the animals we used the retina of the eye as the location for one of the pipet-electrodes,

after it was determined that for these measurements the eye acts as part of the brain. The location of the other pipet-electrode was generally the lumen of the left ventricle of the heart, and in selected cases also the kidney, liver, adrenal gland, bladder, genital organs, rectum, ileocolic junction, stomach, duodenum and spleen. The electrodes were inserted while the animal was under ether anesthesia.

Some significant general observations were made. With blood circulating through it, the polarity of the left ventricle

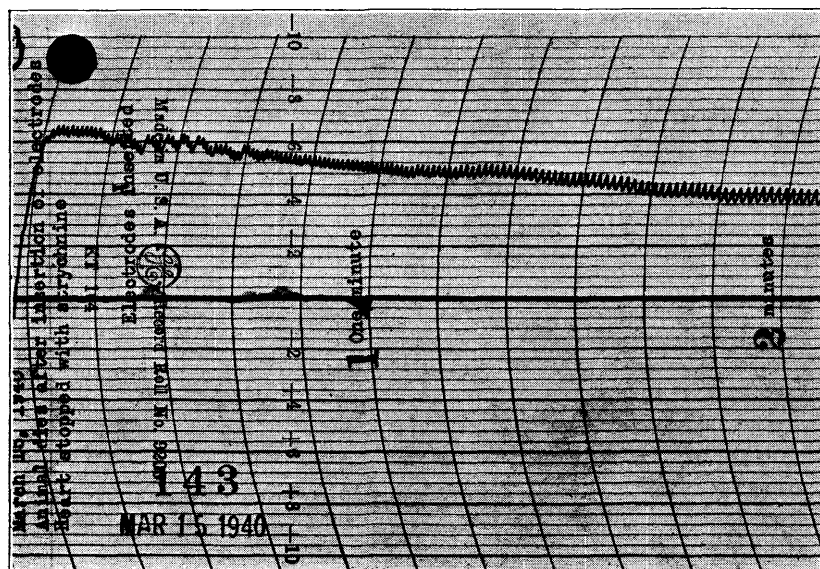


Fig. 2. Death curve in normal rabbit. Interval of time, 10 seconds.

was always negative compared to that of the brain. The polarity of all other organs of the normal animal was also negative compared to that of the brain, with the exception of the stomach.

The potential gradient between eye and left ventricle in almost 200 rabbits was determined to be  $2.28 \pm 0.038$  millivolts.

The potential gradient between eye and right auricle in 10 animals measured  $1.18 \pm 0.073$  millivolts.

If the animal continues to live after the electrodes have been inserted, the potential gradient is essentially maintained during life. If death occurs, the gradient decreases more or less

rapidly. Our experiments have taught us again that it is difficult to determine the exact time of tissue death. Generally, cessation of breathing is referred to as death. However, that does not mean that the other organs of the animal stop functioning at the same time. Many of our records show that after breathing stops, the heart continues to beat for a long time. If the heart slows down, the beats superimposed upon our potential

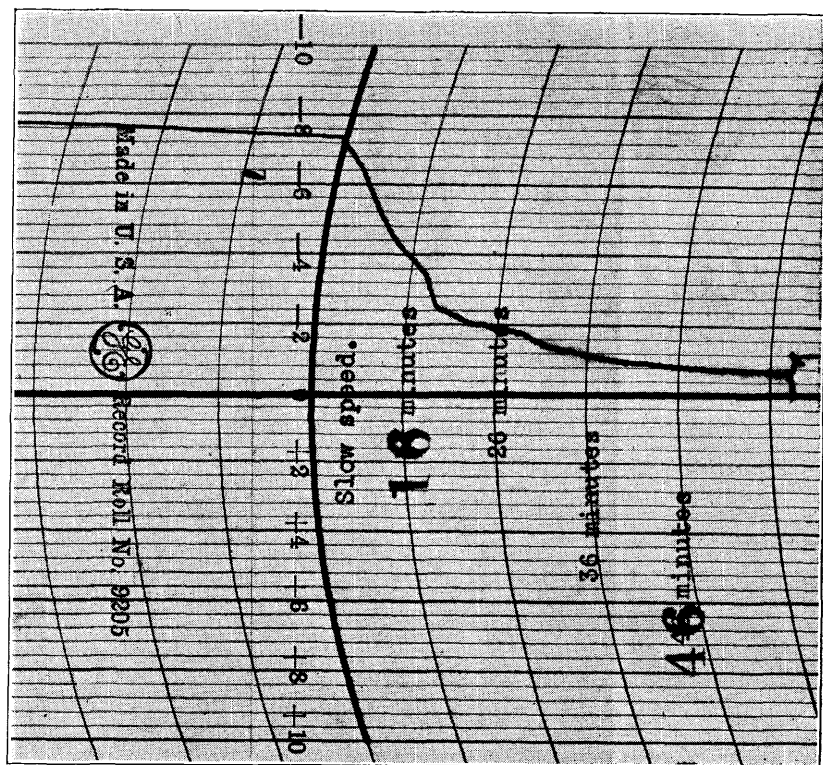


Fig. 3. Death curve in normal rabbit after injection of 2 cc. of chloroform into heart. Interval of time, 10 minutes.

gradient curves continue in many cases even after the main potential difference between heart and eye has disappeared. All other organs also show definite potential gradients long after death, although all of them decrease more or less rapidly after breathing stops. The organs which lose their potentials quickest are the liver and the brain. Then follow the adrenal glands and the organs of the genito-urinary and gastrointestinal tracts.

The kidney potentials seem to be the most stable, and the kidney therewith the longest lived organ of those investigated. According to our observations, we would say that death of all organs has taken place when no potential differences between them and any other part of the body can be determined. This point is not reached until several hours after the animal has stopped breathing. A large series of our records illustrates this fact.

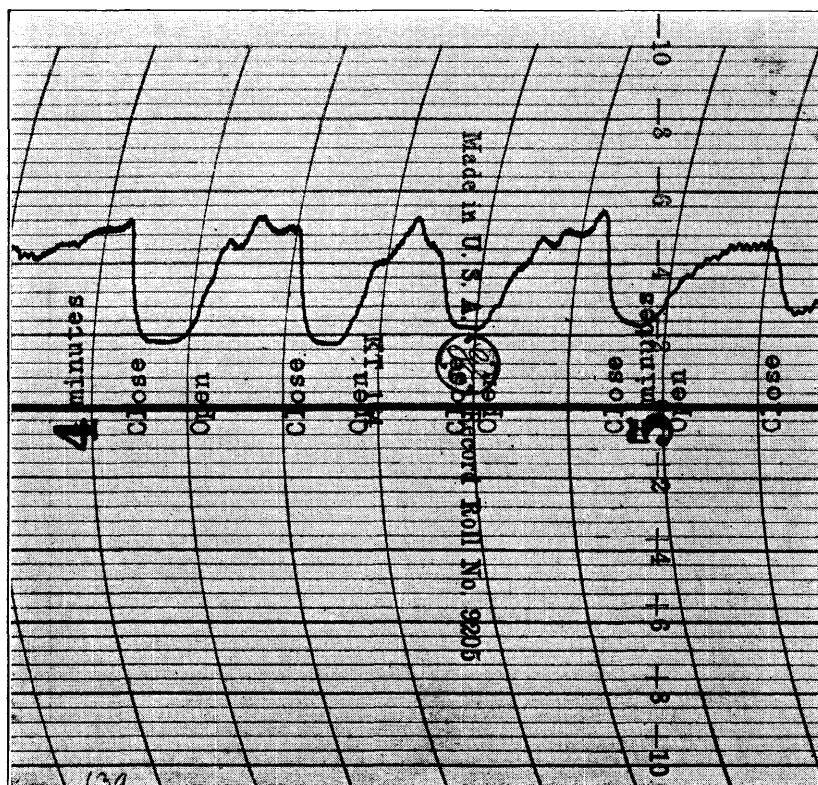


Fig. 4. Effects produced upon potential gradient by clamping and releasing aorta. Interval of time, 10 seconds.

Figure 2 illustrates the drop in the potential gradient after the animal has stopped breathing. In this case the rabbit stopped breathing shortly after the electrodes were inserted in the left ventricle and eye. During the next 7 minutes a definite decrease in the potential difference was noted and, superimposed upon the potential gradient curve, the number and amplitudes

of the heart beats were observed. During the seventh minute, 2 cc. of strychnine, 1:10, was injected directly into the heart, which then stopped beating after one minute.

Figure 3 illustrates a death curve following injection of 2 cc. of chloroform into the heart.

A definite change in potential gradients can be produced by stopping the flow of blood for short intervals. This was done by manipulation of a clamp which was fastened around the aorta

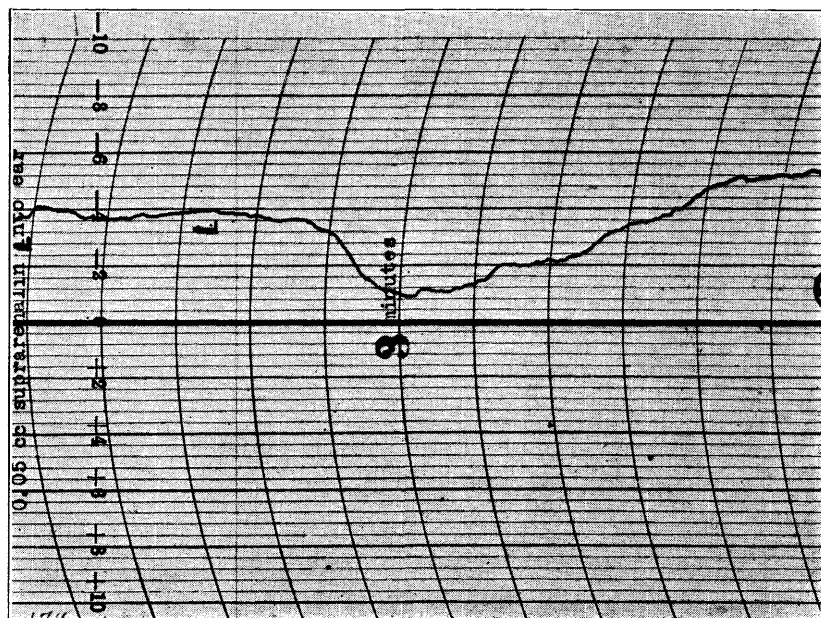


Fig. 5. Effects of adrenalin injected into adrenalectomized rabbit upon potential gradient. Interval of time, 10 seconds.

at its emergence from the heart and which permitted us to stop or start the flow of blood to the heart at will. Figure 4 illustrates the results obtained in one such experiment. Electrodes were inserted into the eye and the left ventricle of a rabbit. In the third minute the blood flow was stopped by closing the clamp, and a definite decrease in the potential difference of over 50 per cent was observed. Upon opening the clamp, the potential returned to the original value. This procedure was repeated eight times during the next two minutes, always with the same result. From the eleventh to the fifteenth minute the same

experiment was repeated about ten times with the same results. The time of stopping the blood flow in each single experiment was approximately 5 seconds. The superimposed heart beats permit the conclusion that the number of beats per minute did not change during the clamping of the aorta.

Figure 5 shows the effect of 0.05 cc. suprarenalin injected into the ear at two minute intervals upon an adrenalectomized rabbit. An initial decrease of the potential gradient about a minute after injection was observed in all cases. This was fol-

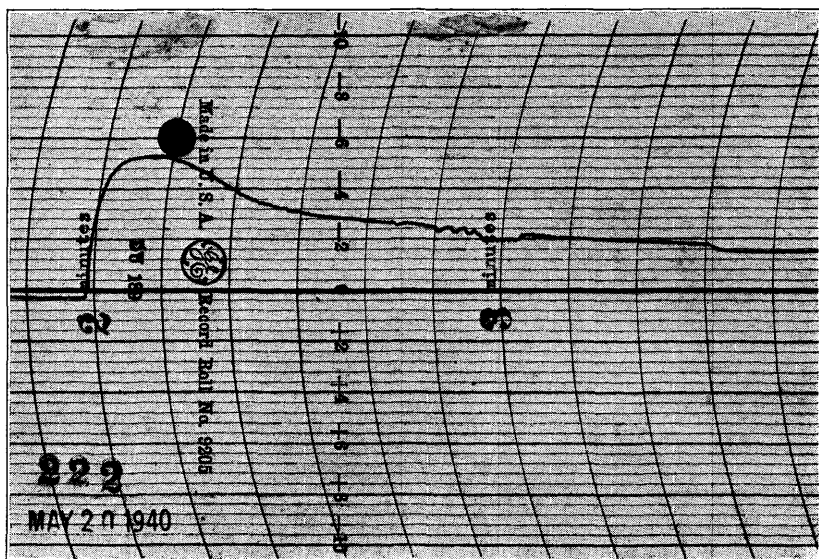


Fig. 6. Effect of pithing upon potential gradient. Rapid drop of potential difference. Interval of time, 10 seconds.

lowed by a rapid increase which carried the potential well beyond the initial value. Repeated doses after the first few injections yielded but a small effect upon the potential gradient.

Adrenalectomized rabbits were chosen for these experiments rather than the normal because only a slight increase in potential occurred in the normal animal. Presumably this is due to the fact that the normal secretion from the adrenal glands in an unoperated animal is sufficiently high to obscure the effects of added adrenalin doses from without upon the potential gradient. It is only after the adrenal glands of a normal rabbit have been



removed that this effect can be observed. Electrical stimulation directly to the adrenal glands of a normal rabbit does, however, produce a marked increase in the potential gradient. It becomes apparent that there are still a number of unknown factors with reference to the adrenalin secretion in the body as well as with reference to the effects of adrenalin introduced from without. It appears that the normally functioning body maintains a definite adrenalin balance which is difficult to disturb. However, if the balance is upset by injury or experimental interference, marked variations in the potential gradients can be observed even after addition of small amounts of adrenalin.

Narcotic agents like cocaine and morphine in small doses produce relatively small effects upon the potential gradients.

If, however, larger doses of the order of  $\frac{1}{2}$  mg. of cocaine were introduced into the ear, rapid fall in potential ending in convulsions and death was observed. Caffeine injected into the ear in small doses (10 mg. in 1 cc. of water) produced considerable increase in the potential gradient and subsequently showed effects in maintaining the potential level similar to that observed with cocaine.

In order to determine whether or not potential gradients could be maintained in the absence of direct nervous connection between the brain and the heart, a number of experiments were carried on in which the animal was pithed and in which the vagus and sympathetic nerves leading to the heart were severed. Figure 6 shows the result of one of these experiments upon the potential gradient measured between the eye and the left ventricle. The animal was pithed and the nerve connections severed after the normal gradient was established, and within one minute the potential difference was decreased to one half. Then it established and maintained itself at this level for at least 10 minutes.

In addition to the experiments involving potential gradients between the heart and the brain as represented by the retina of the eye, a large series of observations, as already indicated, upon the gradients of other organs with reference to the brain was made. The results have not been included in the above discussion. It is sufficient to state, however, that the liver, kidney, adrenal glands, bladder, muscle, rectum, colon, ileocolic junction, stomach, duodenum and spleen all showed a negative polarity in reference to the brain with the exception of the stomach.

Our experiments show that the polarity of the blood in the left ventricle of the heart is negative as compared with that of the brain, and furthermore that changes in the agitation of the blood within the heart are accompanied by corresponding changes in the potential gradient. A number of excitatory as well as narcotizing agents were employed to produce such changes. Other methods of interference with the flow of blood, such as momentary stoppage by mechanical means, were followed by a considerable fall in the electrical potential gradient.

It may be concluded from our experiments that the heart beat plays a definite role in the production and maintenance of the potential difference between heart and brain. Specific changes in these potential gradients may be produced by various mechanical, electrical and chemical means at will.

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